

U.S. DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY - GEOLOGIC DIVISION

PROFESSIONAL/TECHNICAL PERSONNEL RECORD

1. NAME (last) (first) (initial)			2. Birth Date	3. Date prepared	
Price	Leigh	C.	2/27/1944	1/26/93	
4. Duty Station			5. Classification title	Series Grade	
Denver, Colorado			Geologist		14
6. List first and second scientific or technical specialties					
a. Petroleum geology and geochemistry			b. General geochemistry		
7. Other scientific, technical, or special skills (regardless of relation to present position)					
Igneous studies, metamorphism, hydrothermal ore deposits, mineralogy					

8. Education (including secondary schools)

School	Major and minor specialization	Dates Attended	Degree, year or anticipated year
Milliken High School		1960-1962	
Colo. School Mines	Chemistry	1962-1964	
Univ. California Riverside	Chemistry	1964-1966	BS, Chemistry 1966
"	Geology	1964-1973	BS, Geology 1968
"	Geology	1964-1973	MS, Geology 1970
"	Minor: Geochemistry	1964-1973	Ph.D, Geology 1973

9. Civil Service grades and dates Career employee yes

Grade	GS-12	GS-13	GS-14						
Date	1/7/74	7/30/78	6/82						

*Use asterisk for any grade obtained in a management or other nonresearch capacity above GS-12

10. Specialized training (including post-graduate and government courses)
Esso Prod. Research Co., - Structural School
AAPG Clastic Diagenesis School 6/5-6/9 1978 Boulder, CO

11. Memberships in professional societies. List, give dates, and include significant offices held

American Association of Petroleum Geologists 1974-present
Association of Petroleum Geochemical Explorationists 1988-present
Rocky Mountain Association Petroleum Geologists 1991-present

12. SCIENTIFIC AND PUBLIC SERVICE

12a. Lectureships, symposia, invited conference participation. Give dates, nature of entry (were you sought out or did you apply to participate?) and level of participation.

- 1974 Gordon Research Conference on Organic Geochemistry - Invited to attend conference and give paper.
1974 AAPG Conference on Hydrology of Deep Sedimentary Basins - Invited to give paper.
1978 AAPG Short Course on Primary Petroleum Migration - Invited to give paper.
1981 AAPG Research Conference - Temperature environment of oil and gas - Invited to give paper.
1981 Fifth Conference on Geopressured - Geothermal Energy - Invited to give paper.
1982 AAPG Research Symposium at Annual Mtg. - Invited to give paper.
1985 SEPM Research Symposium: Determining the thermal history of sedimentary basins: Methods and case histories, AAPG Annual Meeting - Invited to give paper.
1985 Fourth Conference on Unconventional Methods in Exploration - Invited to give paper at SMU, May 3-4.
1988 - Ninth Annual Research Conference Gulf Coast Section SEPM - Invited to give paper, December 4-7. Gave two papers orally and two papers were published in the Symposium Volume.
1990 - Invited to and gave paper at Gordon Research Conference on Organic Geochemistry (1990) with all expenses paid by Conference. This is a prestigious meeting with only limited invitations offered, much less all expenses paid.
1991 - Invited to lecture at all principal universities and research centers in New Zealand in the fall of 1991, all expenses paid, by the New Zealanders. Approximately 30 lectures on seven topics given.
1991 - Invited to give talk at GSA/ACS cosponsored symposium on high temperature behavior of C₁₅+ HC's at Oct. 1991 National GSA Meeting, San Diego.
1991 - Invited to submit paper and abstract for talk ("On the Origin of Gulf Coast Neogene Oils) for 41st Annual Meeting of Gulf Coast Association of Geologic Societies, Houston, Oct. 16-18, 1991.

1991 - February. Invited to give, and gave, talk to University of California at Berkeley Geology Department and gave 2-day short course to the organic-geochemistry group there.

1991 - July. Invited to give talk at Rocky Mt. Regional AAPG meeting Billings, Montana on Bakken fractured shale oil resource base for a Symposium on Horizontal Drilling.

From 6/1990 to 2/1991 I was invited to speak at five major oil companies on different topics.

1992 Invited to give talk at AAPG Hedberg Research Conference on Surface Geochemical Exploration to be held in 1994 (accepted invitation).

1992 Invited to give talk at ACS meeting on natural gas, to be held 8/93, Chicago (accepted invitation).

I routinely decline 3-6 invitations per year to give papers at symposia or meetings.

Uninvited:

1974 AAPG Annual Meeting - Applied to give paper at meeting.

1977 Third Conference on geopressured-geothermal energy - Applied to give paper at conference.

1978 AAPG Annual Meeting- Applied to give two papers at meeting.

1979 29th Annual Meeting GCAGS - Applied to give paper at meeting.

1992 8th Annual McKelvey Forum - Applied to give paper.

12b. Committees to render scientific judgment. Include scientific review panels, editorial boards, editorships, with dates. Include the capacity in which you served

1980 AAPG Annual Meeting - Poster committee judge and member of abstract review committee.

1992 Editor Journal of Petroleum Geology.

12c. List inventions, patents held, techniques or methods developed or improved. Include dates.

NA

12d. Other committees, special assignments, and administrative duties. Name organization, group, dates, and nature of contributions

I am asked to, and do review, about 5 proposals per year for various organizations (DOE, NSF, etc.)

I am asked to, and do review 15-20 papers per year for outside journals, and/or symposia and conference volumes.

13. Honors, awards, recognition, elected membership. List and give dates.

NDEA Fellowship 1968-1972

Matson Award (Best Paper at National AAPG Mtg.) May 1973. At the time, youngest person ever to receive award.

AAPG Distinguished Lecturer Jan. 1974

AAPG Distinguished Lecturer Oct 1974 - April 1975

Matson Award (AAPG) May 1975. At the time, first person to ever receive award twice.

Best paper 29th Annual Meeting Gulf Coast Association of Geological Societies

Best Paper Branch of Oil and Gas - 1983

Third best talk, 1985 RMAG Luncheon Series

1990 - Branch Promotion Panel

1992 - Committee member on Ray Thomasson's/AAPG's oil resource assessment group for the U.S.

14. CAREER EXPERIENCE

<u>Dates</u>	Brief description of work and position (if USGS, give name of supervisor and organization)
From To	
<hr/>	
<u>December, 1972-December 1973</u>	Esso Production Research Co., P. H. Monaghan. Carried out independent research on the origin and migration of oil and gas.

January, 1974 - Present

USGS, Branch of Oil and Gas, P. R. Rose, R. F. Mast, P. A. Scholle, D. D. Rice, D. Gautier, T. Ahlbrandt. Responsible for designing and carrying out self-directed, unsupervised, original research related to the origin, migration, accumulation and post-accumulation processes of oil and gas to: 1) delineate processes of hydrocarbon (HC) origin and migration which result in conventional HC deposits and develop exploration strategies based on these processes; 2) define the thermal (depth) limits for conventional oil and gas deposits; 3) study unconventional exploration techniques (surface geochemical exploration) for conventional HC deposits based on accumulation/post-accumulation processes; and 4) study the possibility of unconventional HC-based energy resources, among which are: 1) geopressured-geothermal gas, 2) basin-centered gas, 3) deep-basin (high-rank) gas, 4) possible deep-basin conventional oil resources, 5) oil resource bases in self-sourced, fractured shales. Unless otherwise noted, I designed and was/am the sole and/or principal investigator of the projects below.

1974-1978

1. With no guidelines or supervision, I designed and supervised (up to 3 other people on the project) oil- and HC gas-aqueous experimental solubility studies carried out up to temperatures of 400°C, pressures of 30,000 psi, and in the case of oil, with and without methane or carbon dioxide in the system. These are fundamental experimental data which are pivotal to understanding the unanswered question of primary petroleum migration and which should have been available decades ago to the petroleum industry but were never gathered because of the pronounced experimental difficulties involved. The studies were carried to at the F. W. Dickson high pressure laboratory at Stanford University, a lab which I obtained the loan of (uncompensated use), for over two years. The data from this project allowed a definitive appraisal of the conditions in nature under which aqueous molecular solution could or could not act as an agent for primary oil migration. Products (Bib: 3, 4, 7, 10, 16, 20; Abs: 1 (first Matson Award), 4, 10).
2. I designed and carried out a project, with no guidelines or supervision, to test the hypothesis that oils were not generated by, and do not migrate from, fine-grained rocks spatially close to the reservoirs where they are found. Instead, oils were hypothesized to originate from source rocks in the deeper (hotter) areas of petroleum basins ("HC kitchens") and undergo significant vertical or long lateral migration to their reservoirs. In this synthesis study, I examined oil occurrence in all major petroleum basins worldwide to check if worldwide HC occurrences corresponded to my hypothetical model (which they did). From the results of this

project, I advanced three points, very controversial at the time because of a then firm belief among petroleum geologists and most geochemists of a local and low temperature origin of oil. These three points, now accepted paradigms, were: A) In most cases, oil is not generated locally to reservoirs but is from the deeper, hotter areas of basins ("HC kitchens"). B) Major faulting extending to the basin deep is absolutely necessary as a vertical migration conduit from source rocks, thus HC deposits (in certain basinal classes) and should be exclusively associated with major faults. C) In foreland-foldbelt basins, long lateral oil migration (up to 1,000 miles) is common in flat-lying rocks on stable shelves. Specific exploration strategies for different basin types were developed in the products from this project: Products (Bib: 6, 9, 13, 15 (13 and 15 impact papers); Abs: 5 (second Matson Award), 9)

1974-Present

1. I designed and have continuously carried out an unguided, unsupervised research project to delineate and provide evidence for possible controlling parameters of organic metamorphism in nature from: A) petroleum-geochemical analyses of rocks from nature, B) laboratory experiments, and C) literature data where available. Early data I had strongly conflicted with the then current models of organic metamorphism centered around only geologic time and burial temperature controlling first-order reaction kinetics. Five controls (besides burial temperature) have since been identified and are being studied:
 - I. Geologic Time: In a 1983 impact paper (Bib: 21), I took the (unpopular) position and provided substantial evidence that the effect of geologic time (first-order reaction kinetics) had been significantly overestimated in organic metamorphism. This position has currently (1993) been supported by other investigators and the effect of time in computerized models has been scaled back from 1970-1985 estimates. Products: (Bib: 21, 25; Abs: 13, 14).
 - II. Organic Matter (OM) Type: A large body of my unpublished data demonstrates that: A) OM type is a profound and unappreciated controlling parameter of the maturation ranks over which HC generation occurs. B) The widely-quoted maturation ranks estimated for HC generation from the different OM types are in substantial error. C) In sulfur-poor OM, as the original hydrogen content of the OM increases so do the burial temperatures required for HC generation because of increasing kerogen bond strength. Two major papers are in preparation. Products (Bib: 26, 40; Abs: 16, 25).
 - III. Pressure: Laboratory aqueous-pyrolysis experiments conclusively demonstrate that increasing fluid pressures strongly retard all aspects of organic metamorphism including HC destruction. Products (Bib: 42; Abs: 20, 21).
 - IV. Water: Retards HC destruction and enriches kerogen in hydrogen. Laboratory experiments are in progress.
 - V. System Openness: Product escape promotes organic metamorphic reactions, product retention retards it. Laboratory experiments are in progress.
2. I have designed and carried out an unsupervised and unguided project on the detailed petroleum-geochemistry of ultra-deep (to 31,000') high-rank (to $R_o = 7.0-8.0$) well bores to define and provide evidence for the: A) true limits of $C_{15}+$ HC

thermal stability, and B) the ranks over which the different OM types go through (and end) mainstage HC generation. The large data base from this research project provides strong evidence that C₁₅+ HC's are thermally stable for beyond the hypothesized end of the oil window at R_o = 1.35. Although this stand previously was highly controversial, other investigators have recently published evidence supporting the proposition of extended C₁₅+ HC thermal stability, and many petroleum geochemists now orally acknowledge that the HC deadline at R_o = 1.35 is erroneous. The results of this study: A) suggest that in certain basins conventional oil deposits may exist at greater ranks than R_o = 1.35, and thus resource-base estimates of conventional oil reserves may be too low; and 2) suggest that source rocks could "hold" their generated HC's long after generation and finally release them at high ranks when migration routes (faulting) becomes available. An extended thermal stability of HC's to higher maturities also obviously has other strong implications for numerous different petroleum geochemical topics. Products (Bib: 11, 18, 19, 30, 36, 44; Abs: 3, 11, 19, 26.)

Two "sub-projects" are associated with this study:

- 2A. Research to demonstrate that the very strong and large bodies of evidence supporting the hypothesized end of the oil window at R_o = 1.35 are due to other processes operating in petroleum basins. Products (Bib: 14, 32, 45; Abs: 2, 27).
 - 2B. Research delineating the compositional changes which take place in saturated and aromatic HC's as the true HC thermal destruction is approached and gone through by studying bitumens: A) generated by increasingly high-temperature, aqueous-pyrolysis experiments; B) from rocks at the bottom of high-rank wellbores, and C) from metamorphic rocks or rocks from hydrothermal mineral deposits. Products (Bib: 44; Abs: 26).
3. I have carried out an unguided and unsupervised research project to evaluate: A) the presence of a probable deep, geopressured-geothermal energy base in the Gulf Coast; B) the controlling parameters of this energy base; and C) the factors controlling the feasible economic recovery of this energy base. This research strongly suggests that an essentially infinite gas-resource base exists (in some petroleum basins) and is rooted in the presence of a dispersed, free-gas phase at low concentration levels (1-5 volume percent) in the porosity of deeply buried sands and shales in addition to the high levels of gas dissolved in the pore waters of these rocks (determined from my previous solubility studies of gas in water). Wells tapping this resource should flow gas only, at high rates (100-200 MMCF per day) with none of the water production problems associated with the Department of Energy's current geopressured production technique (surface extraction of methane dissolved in brines) in the Gulf Coast. Evidence for the existence of this energy resource base has recently also been provided by the work Roger Anderson at Lamont-Doherty. Anderson has also proposed the same production technique which I previously proposed. Products (Bib: 5, 8; Abs: 6, 7, 8).

1977-1990

I designed unsupervised, unguided research projects to carry out three solubility studies at Idaho State University; approached the researchers there to obtain use of their facilities; and wrote a proposal to DOE to obtain funding for the projects, which were funded by DOE for four years for a little over \$400,000. Furthermore, I was the chief investigator in all these projects. Two of the studies were:

- A) Aqueous methane solubility as a function of variable NaCl content, variable high pressures, variable high temperatures, and the presence of other gases (1977-1981).
- B) The solubility and solution kinetics of methane in waters of variable NaCl concentrations at low and variable temperatures and pressures (1977-1981).

Both of these studies provided fundamental petroleum-geochemical data which are pivotal for a number of different petroleum geochemical topics and were extensions of previous work (1974-1978) I did at Stanford University. I designed the sampling and analytical methods for both studies and helped design the experimental (pressure vessel) approach. These methods and approaches allowed the acquisition of very difficult sets of experimental data which are necessary for valid modeling of different petroleum geological and geochemical topics. Products (Bib: 12, 17; Abs: 12).

- C) The third study involved experimental determination of the solubility of oil in methane gas with water present at variable and elevated temperatures (50°-250°C) and pressures (1,000-15,000 psi). The data from this study demonstrated that primary oil migration by gaseous solution was possible in nature. I designed the experimental approach and sampling and analytical methods for this project which allowed acquisition of another pivotal set of petroleum-geochemical data, which had previously been impossible to take. The data were taken during (1977-1981), however, this aspect of the DOE project was part of a longer term research project of my own which was to delineate the controlling parameters, limitations, characteristics, and applications to nature of primary oil migration by gaseous solution. Products (Bib: 22, 31 (both impact papers), 32; Abs: 15).

1980-Present

1. I have carried out an unsupervised and unguided research project to define the controlling parameters of the generation and accumulation of both conventional and non-conventional (deep-basin, high-rank, and basin-centered) gas deposits and gas resource bases and their respective characteristics. Some important points have resulted from this study: A) Basin-centered gas deposits originate from a specific set of basinal processes and which basins should have these deposits can be specifically predicted. B) Methane in "dry-gas" deposits appears to originate mainly as gas co-generated with C₁₅+ HC's and not from C₁₅+ HC thermal destruction. True high-rank methane deposits from C₁₅+ HC destruction do exist but are rare. C) Many deep portions of most sedimentary basins appear to be closed systems regarding fluid flow such that only limited, or no-, deep-basinal fluid flow occurs when no faulting is present. Thus the size of deep-basin-basin gas resource bases may be

significantly larger than previously thought, and their grade (richness or concentration) also may be much higher than previously thought. By comparing gas data from two unique sources with gas data from nature, unique insights into the natural system are possible, which would not otherwise be the case. These two sources are: A) Gases have been generated and analyzed from six different rocks (of variable OM types) over wide temperature ranges (150°-550°C) in aqueous-pyrolysis experiments I've carried out (see below). B) In a project with Martin Schoell at Chevron, gases are being collected directly from one source rock (Bakken shale) of variable (and known) maturities by taking gas samples co-produced with Bakken oil. This is the first time such a unique set of gases (directly from a source rock) have ever been available. The gas compositional data from both the Bakken oils and aqueous-pyrolysis experiments agree with each other and are much wetter than predicted by existing models. Products (Bib: 34, 45; Abs: 27).

2. I have designed and carried out an unguided, unsupervised research project centered on aqueous-pyrolysis experiments using different organic-rich "source rocks (six as of 1/1993) in small pressure vessels to delineate possible controlling parameters of organic metamorphism in Nature. These experiments are being carried out with widely variable conditions - e.g.: temperature (150°-550°C in 25°C intervals; pressure (100-30,000 psi), time (4 hours to 1 year); water content; and system openness (product escape). Because of the wide scope of both experimental conditions and rock types and because all products (from methane to the asphaltenes) are being collected and analyzed, along with the reacted rocks, this study provides unique data sets which are simply unavailable from other sources. I cannot over emphasize the pivotal applications the different data sets from this study have had, and will continue to have, to different areas of study in petroleum geology and geochemistry. The unique experimental techniques and sampling and analytical methods which I designed allows all reaction products to be trapped and analyzed unlike many other similar studies, which capture only part of the total products. Also, my reaction vessels are smaller and much cheaper than other experimental techniques and thus allow more versatility than many of these other techniques. This study is being jointly carried out with Lloyd Wenger of Exxon Production Research CO. (EPR), and EPR has supplied both funds (about \$17,000 as of 1/93) and manpower (other than Wenger) towards the project. Products (Bib: 40, 42, 45; plus parts of 31, 34, 44; Abs: 20, 21, 25, 27; plus papers in preparation).
3. I have carried out a long-term, unguided, and unsupervised extensive petroleum geochemical study of the Williston Basin, centering on the Bakken shale, but extending to all rocks from the Tertiary to Devonian. This study will, when complete, provide a huge data base with application to: A) resource assessment; B) organic-geochemical modeling; C) basin-wide thermal maturation maps at all depths for the basin; D) testing established organic geochemical precepts and hypothesizing alternate concepts, when necessary; E) evolution of the Williston basin; and F) highlight the Bakken shale as a "type section" for oil resource bases in self-sourced fractured shales. Products (Bib: 23, 28, 29).
A number of related research projects have spun off this study:

1990-Present

- 3A. Previous hypotheses appear erroneous that HC expulsion from organic-rich rocks is very efficient and accumulation is very inefficient such that most generated HC's are lost along secondary migration paths or as leakage to the surface. Instead, data I've gathered from the Williston basin, centered on the Bakken shale, strongly suggest that most generated HC's are retained in, or directly adjacent to, the source rocks that generate them when such source rocks are not faulted. Of the 100-250 billion barrels of oil that the Bakken shales are known to have generated, none has yet been identified in any of the conventional mid-Madison reservoirs of the Williston Basin (see 3B below). This suggests that a huge in-place oil resource base exists in the Williston Basin, a resource base which can be extrapolated to the order of tens to hundreds of trillions of barrels of generated oil for all source rocks in all lower 48 oil basins. As of 1/91, my goals in this project are to provide solid evidence to the scientific community of the existence and magnitude of this in-place oil-resource base such that it will be better appreciated and taken seriously. Long-term goals are to delineate the characteristics and controlling parameters of this resource base such that non-classical drilling, completion, stimulation, and maintenance techniques, which are appropriate to the unique characteristics of this resource base, can be applied to affect possible economic recovery of a significant part of the resource base. This is because it has become quite clear that application of conventional recovery techniques will take only a minute percentage (far less than 1%) of the resource base. On the other hand, only a 10-25% economic recovery of this in-place oil resource base would profoundly affect long-term U.S. energy policies and needs. Products (Bib: 43; Abs: 23, 24).

1991-Present

- 3B. A detailed petroleum-geochemical cross comparison between 15 Bakken-produced oils and 18 mid-Madison produced oils (all from the Williston basin) is being completed. These two groups of oils are different oil families, a conclusion (and the documentation of which) have strong application to: A) the self-sourced, fractured-shale oil resource base (3A, above) in the Bakken shales (and in other source rocks of the of the lower 48); B) a much better understanding of expulsion and accumulation processes, and the controlling parameters thereof, for conventional oil deposits; and C) a better delineation and understanding of "petroleum systems" (source-rock/reservoir plumbing pairs), because the Bakken shale-mid Madison petroleum system, one of our best examples of a "petroleum system", doesn't exist. The importance of the facts to petroleum geochemistry that: 1) the Bakken shales have not sourced the mid-Madison oils in the Williston Basin, and 2) no Bakken oil has yet been found in a mid-Madison reservoir, cannot be overemphasized. (A paper is almost completed).
- 3C. Bakken rock samples from 16 wells (or wells very close, ± 1 section) to the wells which produced the Bakken oils of "3B" (above) have been analyzed by ROCK EVAL for maturity and will be compared with numerous maturity indices of the produced oils. Other Bakken-produced oils and accompanying rock

samples are also being collected for this study. Martin Schoell at Chevron is also running specific carbon isotope analysis on some of these oils. This will be the first time that the maturities of a suite of oils can be directly compared to the maturities of the rocks which are unequivocally known to have sourced the oils. (The rocks have a wide maturity range e.g. - beginning HC generation to post mature.) This study will provide much better insight into both the validity of oil maturity indices currently in use and into the origin of single oil families as observed in the cases of long lateral oil migration on the stable shelves in different basins.

- 3D. The 18 mid-Madison oils of "3B" (above) have been augmented by mid-Madison oils from Manitoba and Saskatchewan (supplied by the Canadian Geological Survey) and also by other oils on the American side of the Williston Basin. These oils represent a full suite of an oil family of a wide maturity range which has undergone known long lateral oil migration and oil geochemical characteristics will be cross compared versus both distance of migration and oil maturity. This study will provide more insight into changes in oil parameters versus both increasing migration distance from the generation site and maturity for a single oil family.
- 3E. A study has been initiated to examine organic facies changes in the Bakken shales for a traverse of immature shales from the 15-20% TOC/800-900 hydrogen index shales in North Dakota, east-northeast to the 5-10% TOC/100-300 hydrogen index shales of Saskatchewan and Manitoba. Also vertical organic facies changes will be examined in immature Bakken shales from single wells as formation contacts are approached (15-20% TOC/800-900 hydrogen index shales go to 1-2 TOC/100-300 hydrogen index shales.) This study will provide well documented insight into the control that organic-matter facies variations have on many different petroleum geochemical parameters of source-rock bitumen and kerogen.

1981-Present

1. I initiated an unsupervised, unguided large petroleum-geochemical source rock study for the California petroleum basins. This study centers around a very large sample base of fine-grained rocks from the California basins which I have assembled, and when complete this study should contribute to: A) the application of organic geochemistry to possible HC exploration of the onshore and highly prospective offshore southern California petroleum basins; B) help delineate the controls that OM type has on organic metamorphism; C) general studies of the California Miocene rocks; and D) a detailed petroleum geochemical data base for three of the richest basins (normalized to sediment amount) in the world (Los Angeles, Ventura, and Southern San Joaquin).

1983-Present

1. I initiated and have overseen an unguided, unsupervised, very large cooperative study of HC microseepage (surface geochemical exploration-SGE). It is recognized that even in mature American Basins, much more oil exists in subtle structural and stratigraphic traps on the stable shelves of certain basins than has yet been found.

Although this oil may represent a possible significant resource base, this oil has gone undiscovered because no good exploration tool exists to look for it. Indeed SGE presently represents the only possible tool. However, SGE is a field which has minimal background scientific research and minimal credibility with explorationists and has previously proven to be impossible to apply as a consistently useful exploration tool.

This study of HC microseepage and SGE has been designed designed to: A) ascertain if it is possible to unambiguously detect HC microseepage and/or its effects on the rocks through which it vertically passes; B) distinguish HC microseepage from other forms of vertical HC migration; and C) determine if anomalies based on measurement of present-day HC microseepage (direct detection), or based on measurement of altered rock properties (indirect detection), have any geometrical coincidence to the surface outline of petroleum deposits, and thus can be used as exploration tools. Three different techniques have been studied in detail: one was an outright failure; another, also a failure, demonstrated why many previous (and present-day) SGE techniques have failed. The third technique, microbial soil surveying appears to be a possible powerful exploration tool. Even a partially successful completion of this project could have a profound impact on: A) oil exploration for stratigraphic, and other subtle, traps in the U.S.; B) specifically delineating areas of by-passed oil (due to reservoir heterogeneity) for enhanced oil-recovery techniques in mature large to giant fields; C) significantly decreasing new field development costs by outlining surface traces of newly discovered fields before development drilling, which would eliminate or greatly decrease the number of expensive and wasteful dry stepout wells around the field; D) a tool to confirm or condemn wildcat drilling sites generated by conventional geologic techniques; E) a research tool to study reservoir heterogeneity, field shapes, and secondary migration paths. Products (Bib: 27 (impact paper in field), 24; Abs: 17; two papers are in preparation).

1989-Present

1. I began an unsupervised, unguided study to delineate compositional changes of aromatic HC's versus maturation rank. This study involves detailed identification of many of the aromatic HC's found in complex distributions in different well-controlled suites of oils, powdered-rock extracts, whole-rock extracts (see below), and bitumens from laboratory (aqueous-pyrolysis) experiments. Compositional changes in these compounds are being examined versus maturation rank. (Maturity index trends within the saturated and gasoline-range HC's are also being run for some of these suites). This study, when complete, should provide much better insight into changes in maturity trends in oils and bitumens.

1990-Present

1. A joint research project with Lloyd Wenger at Exxon Production Research to firmly define changes in biomarkers versus maturity from: A) the aqueous-pyrolysis runs, B) oil suites of variable maturity, and C) different rock sample suites of variable maturity. Work by different investigators has shown that the utility of many

biomarker ratios as maturity indices has been overstated, because both facies (organic matter type) and primary migration effects (and probably other unidentified effects) can strongly change biomarker ratios. This work will contribute to clearing up some of the questions about biomarker utility.

1991-Present

1. I initiated an unguided, unsupervised research project to document and provide evidence of the prefractionation that occurs in source-rock bitumen into an oil-like phase and moves (or is moved) to cracks and parting laminae in source rocks to be poised and ready for migration from the rocks. This fractionation occurs in rocks at all stages of HC generation (including rocks that have not yet begun HC generation) and is probably caused by HC gases. The fractionated oil-like phase is not seen by conventional Soxhlet extraction of powdered rocks, only by Soxhlet extraction of whole (unground rocks). This fractionation has not been observed before because we petroleum geochemists have always extracted powdered rocks, such that the rock matrix (and evidence of bitumen fractionation) was destroyed. It is thus a strong possibility that many of our previous petroleum geochemical analyses could be based on an erroneous analytical technique. This work has profound implications regarding: A) proper laboratory techniques which must be used to achieve valid oil-source rock correlations; B) insights into primary migration mechanisms; C) validity of maturity and source facies indices; and D) origin of small oil deposits at immature ranks. Two study approaches are being used: A) Five Bakken oil-source rock pairs (where oil has been actually produced from the rock samples) are being correlated using rock bitumen from Soxhlet extraction of both powdered rocks and whole rock samples; B) whole rock (core) of varying maturities of Bakken shale (6 each) and coal (5 each) are being successively extracted (8-10 extractions). Powdered samples of the same rock are also being extracted. The extracts are being subjected to full petroleum-geochemical workup to show the significant differences between sequential whole-rock extractions from oil-like in the first extracts to tar-like in the latter extracts and the significant differences between whole rock versus powdered rock extracts. Products (Bib: 41).
2. I initiated a research project to test the hypothesis that source rocks must be physically disrupted by faulting for significant oil expulsion to occur. A study has been completed which documented that increasing basin richness (EUR oil/basin sediment volume or area) strongly correlates with increasing intensity of normal or extensional faulting in the basin deep containing mature HC kitchens. This study covered 85-90% of world's known reserves, and thus supports the above hypothesis. For example, wrench basins, are by far the most structurally-intense basinal class and are also by far the richest basinal class and have the greatest number of oil-productive basins of all basinal classes. Cratonic ("pancake") basins are the least structured basinal class, have the fewest number of producing basins, and by far are the poorest basinal class. This work has strong application to resource assessment as a function of basinal class, frontier exploration evaluation, HC expulsion, and

provides further evidence for the existence of large in-place oil-resource bases in mature (self-sourced) fractured source rocks. Products (Paper in TRU review).

15. BIBLIOGRAPHY

I. Reports

1. Wilson, R. D., Monaghan, P. H., Osanik, A., Price, L. C., and Rogers, M. A., 1973, Estimate of annual input of petroleum to the marine environment from natural marine seepage: *Transactions Gulf Coast Association of Geological Societies*, v. 23, p. 182-193.
2. Wilson, R. D., Monaghan, P. H., Osanik, A., Price, L. C., and Rogers, M. A., 1974, Natural marine oil seepage: *Science*, v. 184, p. 857-865.
3. Price, L. C., 1976, The aqueous solubility of petroleum and petroleum-forming hydrocarbons as applied to the origin and primary migration of petroleum: *American Association Petroleum Geologists Bulletin*, v. 60, no. 2, p. 213-244.
4. Price, L. C., 1977, Aqueous solubility of petroleum as applied to its origin and primary migration—Reply: *American Association Petroleum Geologists Bulletin*, v. 61, p. 2149-2156.
5. Price, L. C., 1978, Crude oil and natural gas dissolved in deep, hot geothermal waters of petroleum basins—a possible significant new energy source: *Proceedings of the Third Conference on Geopressured-Geothermal Energy*, Meriwether, J., ed., Lafayette, Louisiana, Nov. 16-18, 1977, v. 1, p. G1167-G1249.
6. Price, L. C., 1978, Hot deep origin of petroleum—Deep basin evidence and application: U.S. Geological Survey Open-File Report 78-1020, 69 pages, 21 figures, 9 tables.
7. Price, L. C., 1978, Aqueous solubility of nitrogen at 290°C as a function of pressure: U.S. Geological Survey Open-File Report 78-1070, 5 pages, 1 fig., 1 table.
8. Price, L. C., 1978, Deep geopressured waters—an alternate energy source?: *Oil and Gas Journal*, December 18, p. 88-91.
9. Price, L. C., 1978, Hot deep origin of petroleum—shelf and shallow-basin evidence and application: U.S. Geological Survey Open-File Report 78-1021, 43 pages, 23 figures, 1 table.
10. Price, L. C., 1979, The aqueous solubility of methane at elevated pressures and temperatures: *American Association of Petroleum Geologists Bulletin*, v. 63, no. 9, p. 1527-1533.
11. Price, L. C., Clayton, J. L., and Rumen, L. L., 1979, Organic geochemistry of a 6.9 kilometer-deep well, Hinds County, Mississippi: *Gulf Coast Association Geological Societies, Transactions*, v. 29, p. 352-370.
12. Blount, C. W., Price, L. C., Wenger, L. M., and Tarullo, M., 1980, Methane solubility in aqueous NaCl solutions at elevated temperatures and pressures: *United States Gulf Coast Geopressured-Geothermal Energy Conference, 4th, Proceedings*, p. 1225-1262.
13. Price, L. C. 1980, Utilization and documentation of vertical oil migration in deep basins: *Journal of Petroleum Geology*, v. 2, p. 353-387.

14. Price, L. C., 1980, Crude oil degradation as an explanation of the depth rule: *Chemical Geology*, v. 28, p. 1-30.
 15. Price, L. C., 1980, Shelf and shallow basin as related to hot-deep origin of petroleum: *Journal of Petroleum Geology*, v. 3, p. 91-116.
 16. Price, L. C., 1981, Aqueous solubility of crude oil to 400°C, 2000 bars pressure in the presence of gas: *Journal of Petroleum Geology*, v. 4, p. 195-223.
 17. Price, L. C., Blount, C. W., MacGowan, D., and Wenger, L., 1981, Methane solubility in brines with application to the geopressed resource, *in* Bebout, D. G., and Bachman, A. L., eds., *Proceedings, 5th Conference on Geopressed-Geothermal Energy U.S. Gulf Coast: Louisiana State University, October 13-15*: p. 205-214.
 18. Price, L. C., Clayton, J. L., and Rumen, L. L., 1981, Organic geochemistry of the 9.6 km Bertha Rogers #1, Oklahoma: *Journal of Organic Geochemistry*, v. 3, p. 59-77.
 19. Price, L. C., 1982, Organic geochemistry of 300°C, 7-km core samples, South Texas: *Chemical Geology*, v. 37, p. 205-214.
 20. Price, L. C., 1982, Primary petroleum migration by molecular solution—consideration of new data: *Journal of Petroleum Geology*, v. 4, p. 89-101.
-
21. Price, L. C., 1983, Geologic time as a parameter in organic metamorphism and vitrinite reflectance as an absolute paleogeothermometer: *Journal of Petroleum Geology*, v. 6, no. 1, p. 5-38.
 22. Price, L. C., Wenger, L.M., Ging, T.G., and Blount, C.W., 1983, Solubility of crude oil in methane as a function of pressure and temperature: *Organic Geochemistry*, v. 4, no. 3/4, p. 201-221.
 23. Price, L. C., Ging, T.G., Daws, T. A., Love, A. H., Pawlewicz, M. J., and Anders, D. E., 1984, Organic metamorphism in the Mississippian-Devonian Bakken shale North Dakota portion of the Williston basin, *in*, Woodward, Jane, Meissner, F.F., and Clayton, J.L., eds., *Hydrocarbon source rocks of the greater Rocky Mountain region: Rocky Mountain Association of Geologists*, p. 83-133.
 24. Price, L. C., 1985, A critical overview of and proposed working model for hydrocarbon microseepage: U.S. Geological Survey Open-File Report 85-271, 86 p.
 25. Price, L. C., 1985, Geologic time as a parameter in organic metamorphism and vitrinite reflectance as an absolute paleogeothermometer: Reply: *Journal of Petroleum Geology*, v. 8, no. 2, p. 233-240.
 26. Price, L. C., and Barker, C.E., 1985, Suppression of vitrinite reflectance in amorphous rich kerogen—A major unrecognized problem: *Journal of Petroleum Geology*, v. 8, no. 1, p. 59-84.
 27. Price, L. C., 1986, A critical overview and proposed working model of surface geochemical exploration, *in* Davidson, M.J., ed., *Unconventional methods in exploration for petroleum and natural gas, IV: Dallas, Tex., Southern Methodist University Press* p. 245-304.

28. Price, L. C., Daws, T. A., and Pawlewicz, M. J., 1986, Organic metamorphism in the Lower Mississippian-Upper Devonian Bakken shales, Part I; Rock-Eval pyrolysis and vitrinite reflectance: *Journal of Petroleum Geology*, v. 9, no. 2, p. 125-162.
29. Price, L. C., Ging, T. G., Love, A. H., and Anders, D. E., 1986, Organic metamorphism in the Lower-Mississippian Upper-Devonian Bakken shales, Part II; Soxhlet extraction: *Journal of Petroleum Geology*, v. 9, no. 3, p. 313-342.
30. Price, L. C., 1988, The organic geochemistry (and causes thereof) of high-rank rocks from the Ralph Lowe-1 and other well bores: U.S. Geological Survey Open-File Report 88-651, 49 p.
31. Price, L. C., 1989, Primary petroleum migration from shales with oxygen-rich organic matter: *Journal of Petroleum Geology*, v. 12, no. 3, p. 289-324.
32. Price, L. C., 1989, Hydrocarbon generation and migration from Type III kerogen as related to the oil window: U.S. Geological Survey Open-File Report 89-194, 41 p.
33. Price, L. C., 1989, Louisiana oil-oil correlation by isocyclic, aromatic, and gasoline range hydrocarbons, with an appendix of organic-geochemical rock data from selected wells in the Gulf Coast. U.S. Geological Survey Open-File Report 89-358, 91 p.
34. Price, L. C., 1989, Organic geochemistry of deep gas accumulations, Appendix C, *in*: Rice, D. D., Distribution of natural gas and reservoir properties in the continental crust of the United States: Gas Research Institute Final Report Contract No. 5087-260-1607, distributed by the Department of Commerce, NTIS 89/0188, p. 73-91.
(Branch Chief approval 13-Sept-1989, and CTR log-in 14-Sept-1989.)
35. Price, L. C., 1990, Crude oil characterization at Caillou Island, Louisiana by "generic" hydrocarbons, *in* Gulf Coast Oil and Gases: Gulf Coast Section, Society of Economic Paleontologists and Mineralogists, Ninth Annual Research Conference Symposium Volume, p. 237-262.
36. Price, L. C. and Clayton, J. L., 1990, Reasons for and significance of deep, high-rank hydrocarbon generation in the South Texas Gulf Coast, *in* Gulf Coast Oil and Gases: Gulf Coast Section, Society of Economic Paleontologists and Mineralogists, Ninth Annual Research Conference Symposium Volume, p. 105-138.
37. Price, L. C., 1991, Considerations of oil origin at Caillou Island and elsewhere in the Gulf Coast: U.S.G.S. Open-File Report 91-307, 53 p.
38. Price, L. C., [submitted], Surface geochemical exploration for petroleum--A suggested functional model: American Association of Petroleum Geologists Bulletin, 79 manuscript pages, 15 figures. (Branch Chief approval, 04/10/87; BTR log-in, 04/13/87.)
39. Price, L. C., and Clayton, J. L., 1992, Extraction of whole vs. ground source rocks: Fundamental petroleum geochemical implications including oil-source rock correlation: *Geochemical Acta*, v. 56, p. 1213-1222.

40. Wenger, L. M., and Price, L. C., 1991, Differential petroleum generation and maturation paths of the different organic matter experimental temperatures: European Association of Organic Geochemists 15th International Meeting, Advances and applications in the natural environment: Organic Geochemistry, Manchester Press, p. 335-339.
41. Price, L. C., and Clayton, J. L., 1992, Extraction of whole vs. ground source rocks: Fundamental petroleum geochemical implications including oil-source rock correlation: *Geochemical et Cosmochimica Acta*, v. 56, p. 1212-1222.
42. Price, L. C., and Wenger, L. M. 1992, The influence of pressure on petroleum generation and maturation as suggested by aqueous pyrolysis: in *Advances in Organic Geochemistry 1991*, Organic Geochemistry, v. 19, p. 141-159.
43. Price, L. C., and Le Fever, J. A., 1992, Does Bakken horizontal drilling imply huge oil-resource bases in fractured shales? in Schmoker, J., ed., *Geological Studies Relevant to Horizontal Drilling, Western North America: Rocky Mountain Association Geologists*, p. 199-214.
44. Price, L. C., [accepted], Hydrocarbon thermal stability in nature—Limits, evidence, characteristics, and possible controls: *Geochimica et Cosmochimica Acta*, 68 ms. p., 18 figs, 1 table.
(Branch Chief approval 22-Jun-1992, and CTR log-in 6-Jul-1992.)
45. Price, L. C., 1992, Hydrocarbon thermal destruction as related to high-rank, deep-basin gas resource bases, in, Dyman, T. S., (ed.), *Geologic controls and resource potential of natural gas in deep sedimentary basins in the United States*, U.S.G.S. Open-File Report 92-524, p. 173-277. (55 ms p., 41 figs, 8 tables.)
46. Dickinson, W. W., Newman, R. H., Collen, J. D., Price, L. C., and Law, B. E., 1992, ¹³C NMR spectra from Mississippian-Devonian Bakken Shale, Williston basin, North Dakota, and Upper Cretaceous Fruitland Coal, San Juan basin, New Mexico, U.S.A.: Wellington, New Zealand, Victoria University of Wellington, Research School of Earth Sciences, Geology Board of Studies Publication No. 8, 31 p.

II. ABSTRACTS

1. Price, L. C., 1973, Solubility of petroleum in water as a function of temperature and salinity, and its significance to primary petroleum migration: American Association Petroleum Geologists Bulletin, v. 57, p. 801.
2. Price, L. C., 1974, Implications of petroleum maturation and degradation to its origin: Paper presented at the Gordon Research Conference on Organic Geochemistry, August 19-23, Abstracts with program.
3. Price, L. C., 1974, The evaluation of oil possibilities in high-pressure deposits in deep sedimentary basins: Paper presented at the AAPG Conference on Hydrology of Deep Sedimentary basins, Oct. 7-11, Abstracts with programs.
4. Price, L. C., 1974, Solubility of petroleum in water and its significance to petroleum migration, American Association Petroleum Geologists Distinguished Lecture Tour, 1974-75, given at approximately 30 geologic societies and universities: American Association Petroleum Geologists Bulletin, v. 58, p. 2217.
5. Price, L. C., 1975, Evidence for and use of the model of a hot deep origin of petroleum in exploration, American Association Petroleum Geologists Annual meetings, Abstracts, v. 2, p. 60-61.
6. Price, L. C., 1975, Crude oil dissolved in deep geothermal waters of petroleum basins--possible new energy source: American Association Petroleum Geologists Bulletin, v. 59, p. 920.
7. Price, L. C., 1977, Crude oil and natural gas dissolved in deep, hot geothermal waters of petroleum basins--a possible significant new energy source: Paper presented at the Third Annual Conference on Geopressured-Geothermal Energy, Nov. 16-18. Abstracts with programs.
8. Price, L. C., 1978, Crude oil and natural gas dissolved in deep, hot, geothermal waters of petroleum basins--a possible significant new energy source (abs.): American Association of Petroleum Geologists Bulletin, v. 62, no. 3, p. 555-556.
9. Price, L. C., 1978, New evidence for a hot, deep origin and migration of petroleum: American Association of Petroleum Geologists Bulletin, v. 62, no. 3, p. 556.
10. Price, L. C., 1978, Some physical and chemical constraints on primary petroleum migration: American Association of Petroleum Geologists Short Course, Annual Meeting Program, April 9-12, p. 106.
11. Price, L. C., Clayton, J. L., and Rumen, L. L., 1979, Organic geochemistry of a 6.9 kilometer deep well, Hinds County, Mississippi: American Association of Petroleum Geologists Bulletin, v. 63, no. 7, p. 610.
12. Blount, C. W., Wenger, L. M., Tarullo, M., and Price, L. C., 1980, Methane solubility in aqueous NaCl solutions at elevated temperatures and pressures: Geological Society of American Rocky Mountain Section Meeting, Ogden, Utah, May 15-17, 1980, Programs with Abstracts.
13. Price, L. C., 1981, Organic geochemistry and petroleum exploration--problems?: American Association of Petroleum Geologists Bulletin, v. 65, no. 7, p. 1363.
14. Price, L. C., 1982, Time as a factor in organic metamorphism, and the use of vitrinite reflectance as an absolute paleogeothermometer: American Association of Petroleum Geologists Bulletin, v. 66, no. 5, p. 619.